



An improved tip-loss correction based on vortex code results

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Abstract

Standard blade element momentum(BEM) codes use Prandtl's tip-loss correction which relies on simplified vortex theory under the assumption of optimal operating condition and no wake expansion. A new tip-loss correction for implementation in BEM codes has been developed using a lifting-line code to account for the effect of wake expansion, roll-up and distortion under a wide variety of operating conditions. A database of tip-loss corrections is established for further use in a BEM code. Using this model a more physical representation of the flow and hence a better assessment of the performance of the turbine by BEM codes is expected.

Motivations

Tip-losses are of high concern for wind energy:

- Load reduction at the tip => power loss(lever arm rule)
- Large rotor design is driven primarily by load and tip deflection constraints. The tip-loss factor has a strong influence on the required blade stiffness and hence its mass and cost.
- BEM results highly dependent on tip-loss correction used: variability of C_p and AEP of $\pm 5\%$ (see [3] and Figure 2)

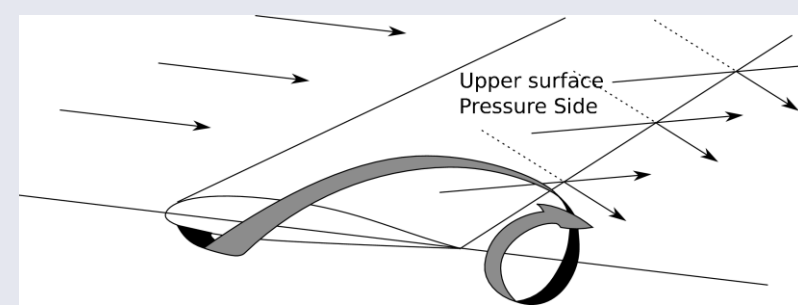


Figure 1: Formation of tip-vortex

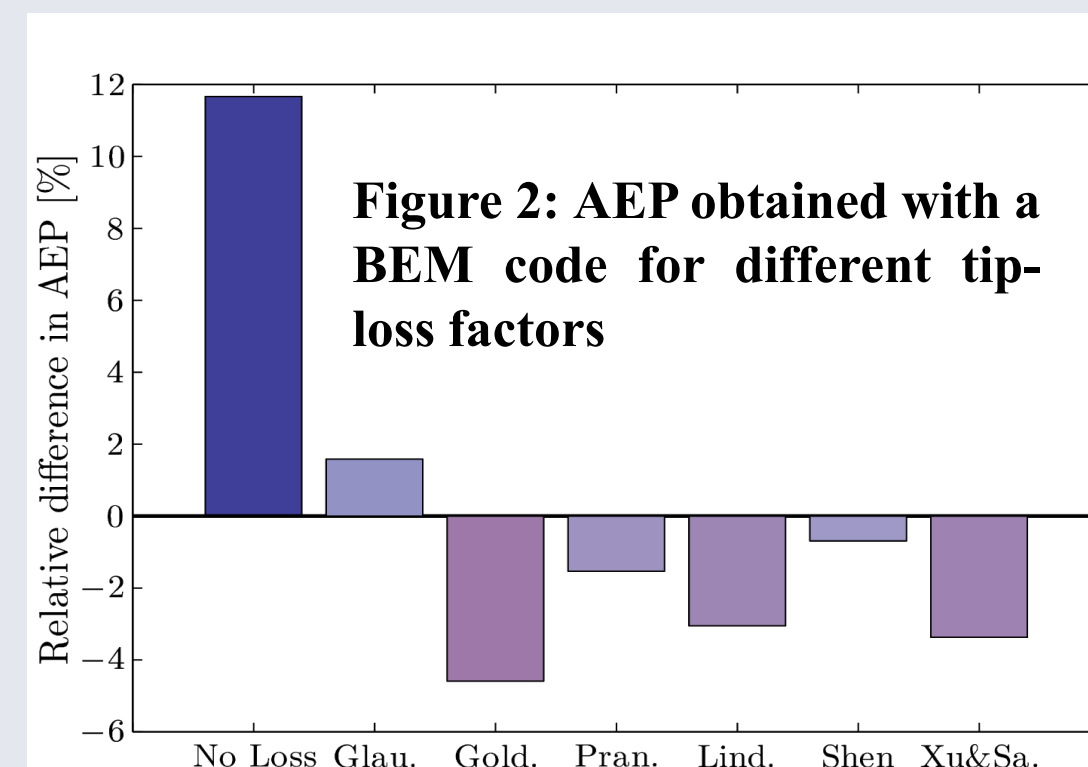


Figure 2: AEP obtained with a BEM code for different tip-loss factors

➔ A need for improved tip-loss corrections and a better insight in tip-losses

Objective

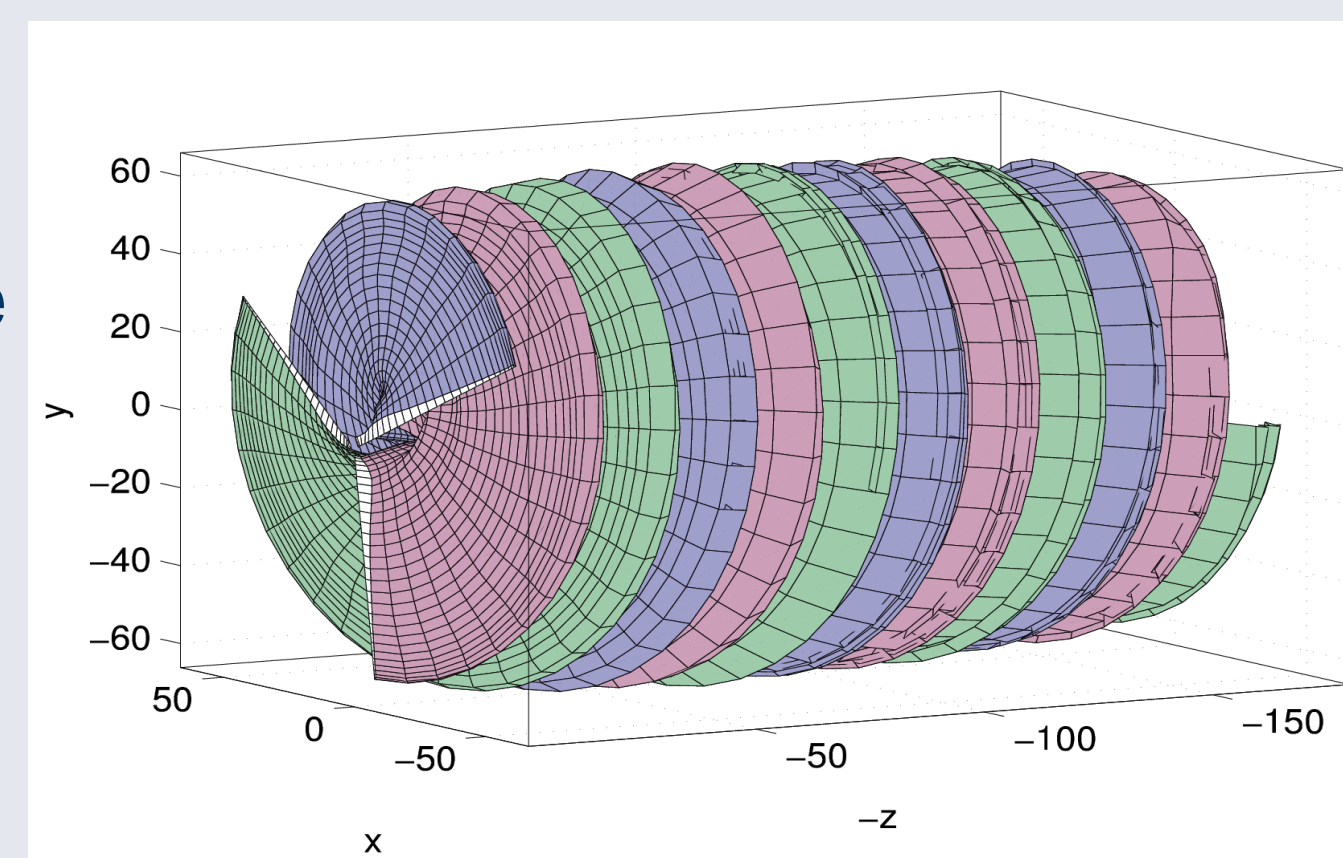
The objective of this study is to determine a more realistic and accurate tip-loss function than Prandtl's[1] or Goldstein's[2] for an implementation in BEM codes at small computational cost. Main effects found for wind turbines that are not accounted for in the analytical derivations are: expansion, roll-up and distortion of the wake. The new tip-loss function should include these effects for a more physical representation of the flow and hence a better assessment of the performance of the turbine by BEM codes.

Approach

Given that most of the vorticity found in the wake can be assumed to be concentrated in vortex sheets and tip-vortices, a great descriptive and predictive tool for wake dynamics is the vortex theory. Applied analytically, this theory led to the development of important theorem from Munk and Betz and the later work from Prandtl and Goldstein. In numerical applications, vortex theory gives rise to the development of different vortex codes.

➔ Use an unsteady free-wake lifting-line vortex code

Figure 3: Wake distortion, expansion and roll-up as obtained by a lifting-line code



Methodology

1. Find a set of parameters characteristic of a wide range of simulations:
➔ { Circulation shape, CT, lambda }

2. Find a way to parametrize the circulation shape:
➔ Use Bézier curves (see Figure 4)

3. Establish a database of tip-loss corrections using a vortex code for each set of parameters

- Run a specific BEM code to determine the relation between circulation amplitude and CT
- Run Vortex Code for given parameters
- Compute Tip-loss function
- Store in database

4. Use this database of tip-corrections within a new BEM code

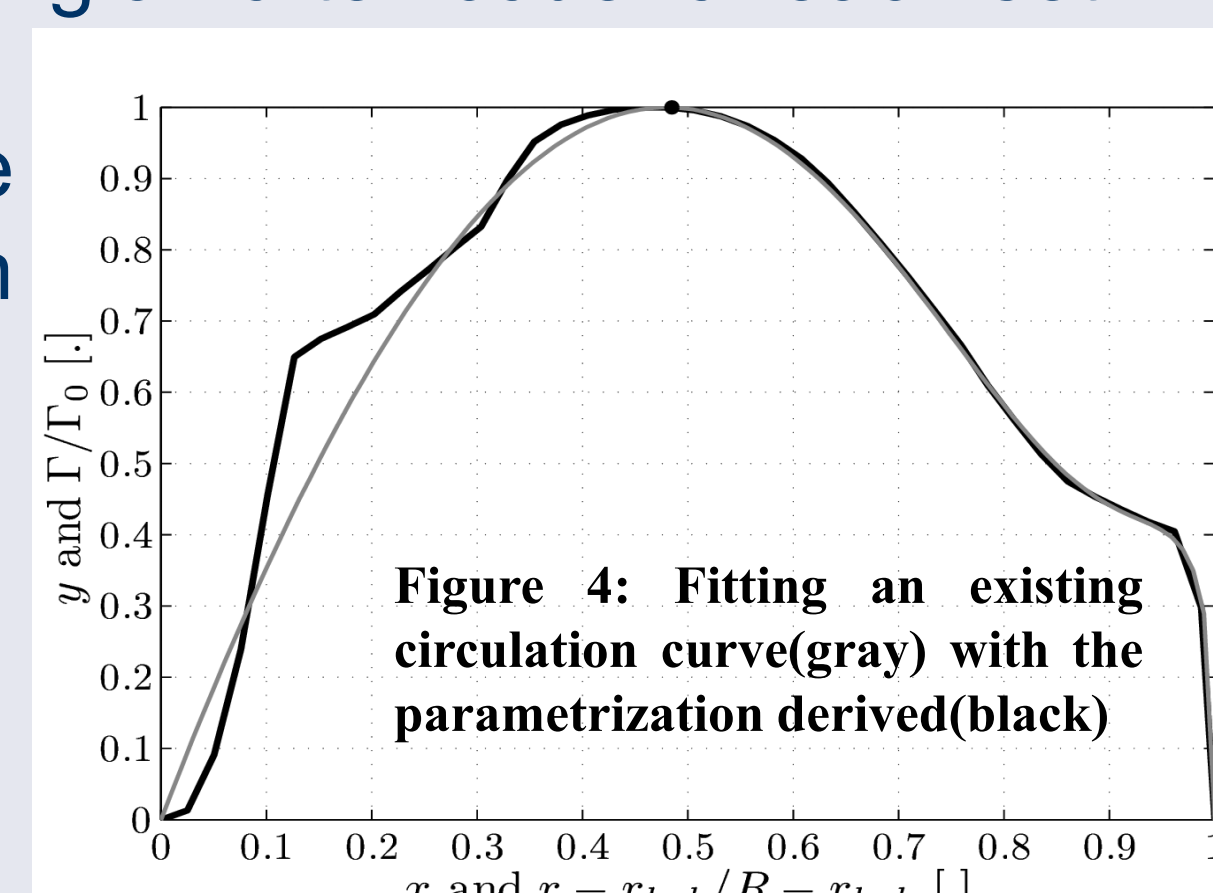


Figure 4: Fitting an existing circulation curve(gray) with the parametrization derived(black)

Sensitivity analysis

Results from the sensitivity analysis gave the following trends:

- Coherent behavior with increasing blade number (Figure 5)
- Negligible dependency in twist and chord
- Negligible dependency with respect to vortex core
- Negligible dependency with respect to grid resolution
- Strong dependency on database parameters:
Tip-speed ratio (Lambda on Figure 6) > CT > Circulation shape

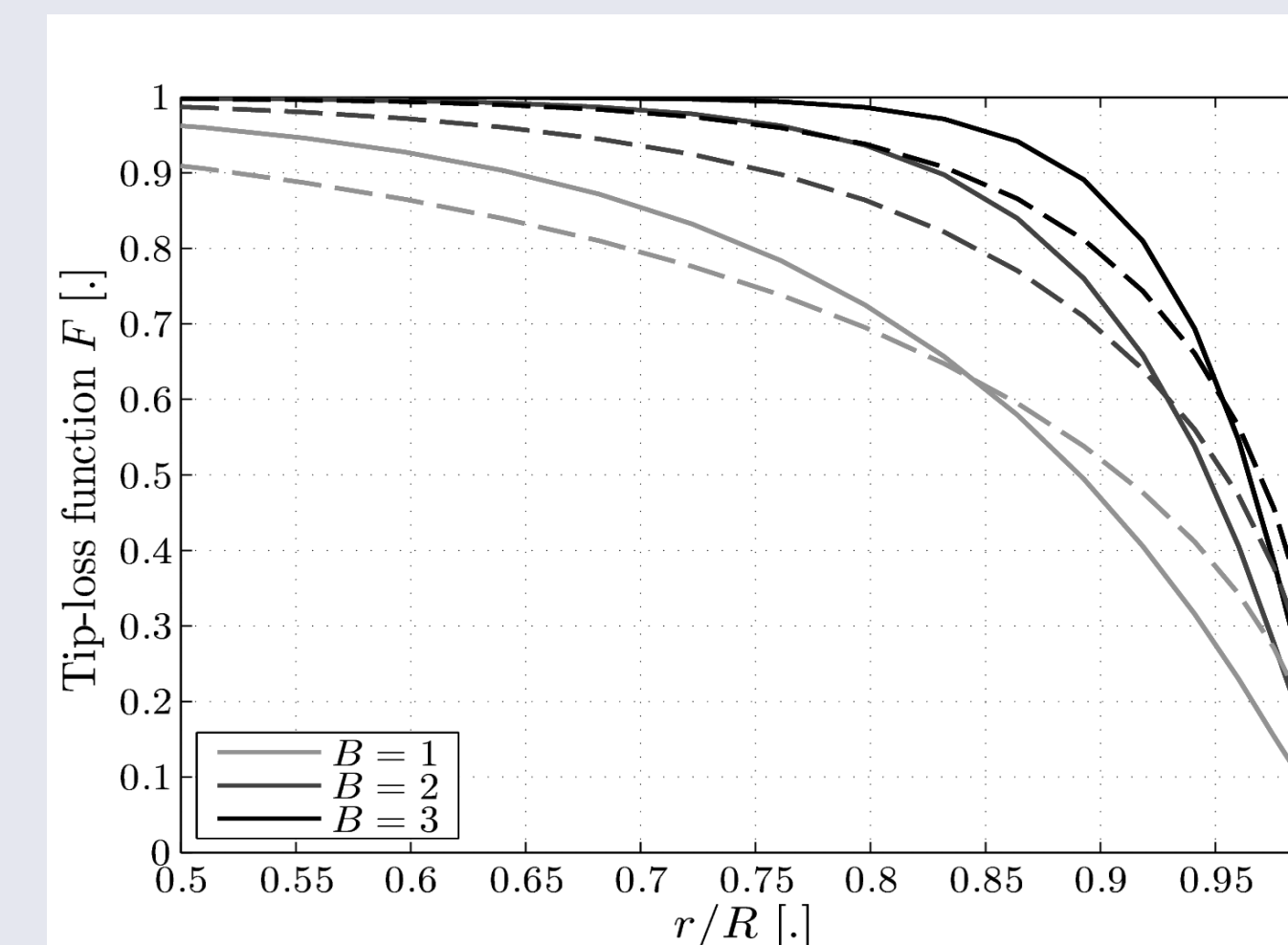


Figure 5: Influence of the number of blades. Glauert tip-loss factor(dashed) – New tip-loss factor (plain)

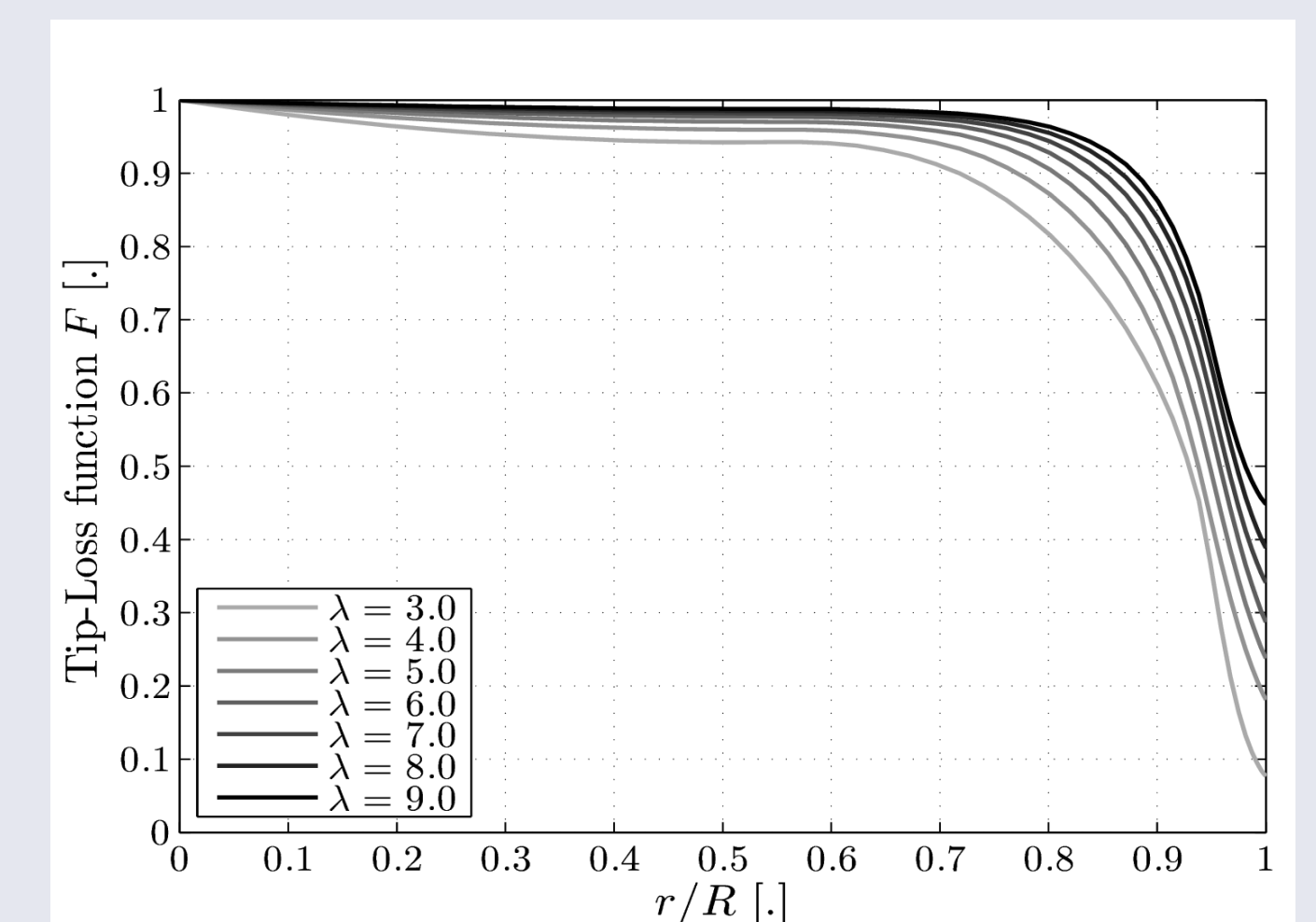


Figure 6: Influence of tip-speed ratio on the tip-loss factor obtained with the vortex code

Results

Results from the new BEM code are compared to a vortex code used as a predictive tool on Figure 8. Comparison of computational time is shown on Table 1. The differences in tip-loss factor implies difference in: root bending moments, tip-deflections, power coefficient, AEP(within a few percents), blade stiffness, blade mass and blade cost.

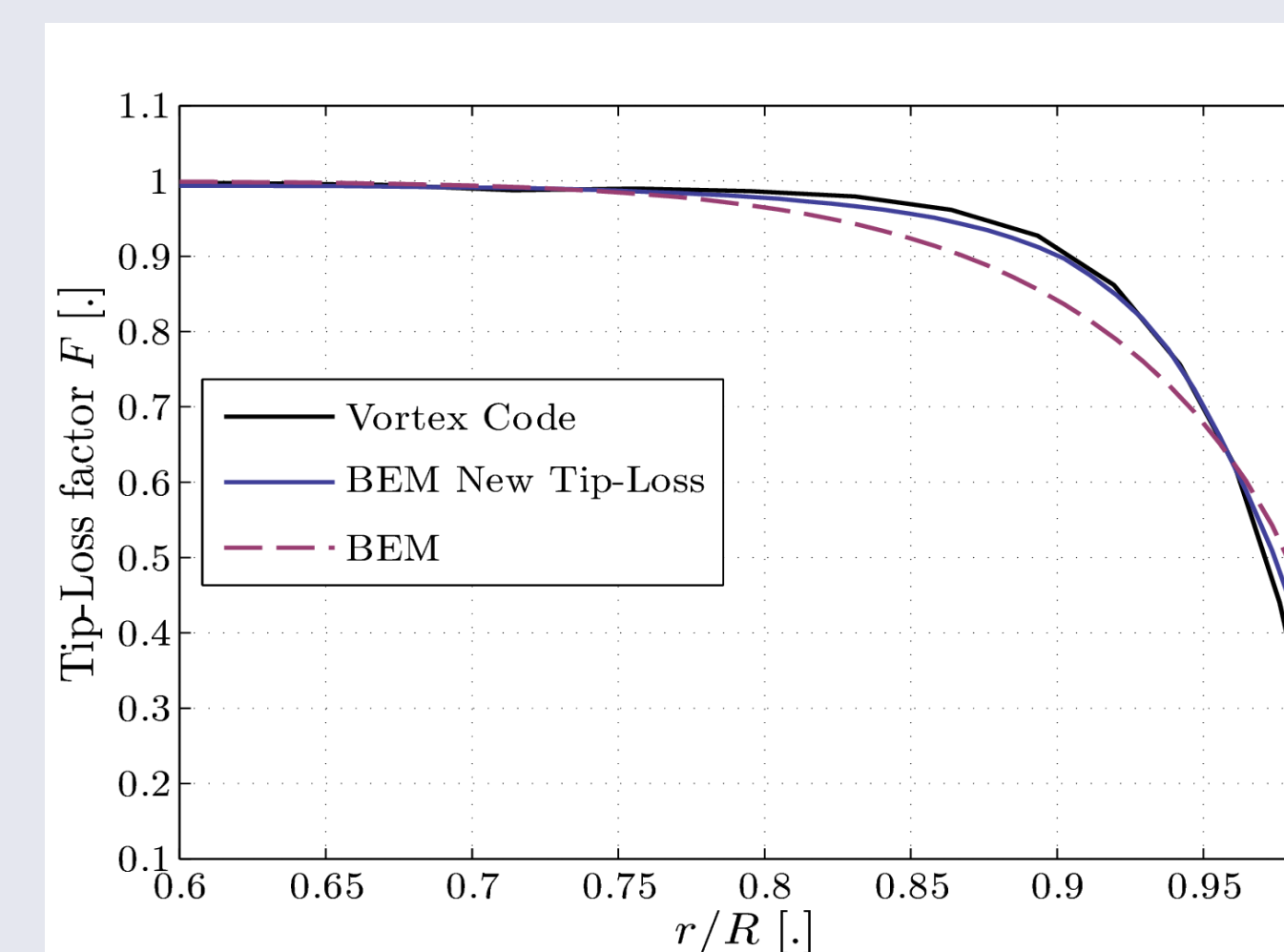


Figure 8: Tip-loss factor as found by the different codes: BEM (Glauert [4]), BEM(New tip-loss) and the vortex code as a predictive tool (using airfoil data)

Table 1 : Rough comparison of computational time

BEM	BEM(New)	Vortex Code	CFD
1s	2s	12min	1 day (x72)

Conclusions

Shortcomings of the new-tip loss correction

- No analytical expression
- Limited to a set of computed characteristics cases

Advantages of the new tip-loss corrections with respect to Prandtl's or Goldstein's theory:

- Accounts for wake expansion, roll-up and distortion
- Not restricted to optimal conditions and low CT. Reproduce optimal results and is valid for a wide variety of operating conditions
- Direct computation at the rotor (does not involve far-wake parameters [3])

Opportunities for improved blade design

- Reproduces well the results from a predictive vortex code:
➔ the goal of improving the physical modeling of tip-losses in BEM codes has been reached
- Small computational cost
➔ can be used in optimization procedures and blade design tools

References and Acknowledgments

- [1] A. Betz. - L. Prandtl - Schraubenpropeller mit geringstem energieverlust - mit einem zusatz von l. prandtl. Göttinger Klassiker der Strömungsmechanik Bd. 3, pages p68–88, 1919. (in German).
- [2] S. Goldstein. On the vortex theory of screw propellers. Technical report, St. John's College, Cambridge, January 1929.
- [3] E. Branlard. Wind turbine tip-loss corrections. Master's thesis, Risø-DTU, Siemens Energy Inc., September 2011.
- [4] H. Glauert. Airplane propellers, division I. Aerodynamic Theory, 4:p169–360, 1935.

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